SOLAR/1012-79/14

Solar Energy System Performance Evaluation

J. D. EVANS, INC., HOUSE A
SINGLE-FAMILY RESIDENCE
Columbia, Maryland
November 1978 Through March 1979

U.S. Department of Energy

National Solar Heating and
Cooling Demonstration Program

National Solar Data Program

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

J. D. EVANS, INC., HOUSE A
COLUMBIA, MARYLAND

NOVEMBER 1978 THROUGH MARCH 1979

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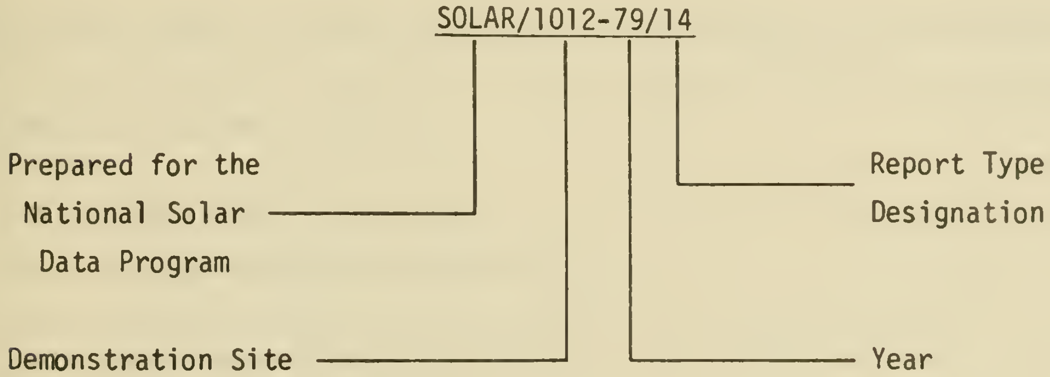
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the J. D. Evans, Inc., House A project site is designated as SOLAR/1012-79/14. The elements of this designation are explained in the following illustration.



- o Demonstration Site Number:

  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- o Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.

- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- Solar Project Description
- Design/Construction Report
- Project Costs
- Maintenance and Reliability
- Operational Experience
- Monthly Performance
- System Performance Evaluation

The International Business Machines (IBM) Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the Solar Energy System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance

represents over 8,000 discrete measurements obtained each month by the National Solar Data Network (NSDN). Documents referenced in this report are listed in Section 6, "References." Numbers shown in brackets refer to reference numbers in Section 6. All other documents issued by the National Solar Data Program for the J. D. Evans, Inc., House A solar energy system are listed in Section 7, "Bibliography".

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the J. D. Evans, Inc., House A solar energy system. The analysis covers operation of the system from November 1978 through March 1979. The J. D. Evans, Inc., House A solar energy system provides domestic hot water preheating and space heating to a single-family residence located in Columbia, Maryland. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using a system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data for the reporting period were collected by the NSDN [1]. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

2. SUMMARY AND CONCLUSIONS

This section provides a summary of the performance of the solar energy system installed at J. D. Evans, Inc., House A, located in Columbia, Maryland for the period November 1978 through March 1979. This solar energy system is designed to support the domestic hot water and space heating loads. A detailed description of J. D. Evans, Inc., House A solar energy system operation is presented in Section 3.

2.1 Performance Summary

The solar energy site was occupied from November 1978 through March 1979. The solar energy system operated continuously during this reporting period, and there had been no significant solar energy system or system operational anomalies. When compared with expected system thermal performance as derived from a modified f-chart analysis (see Sections 5 and 5.2 for details), the system performed somewhat poorer than expected. Useful data were not available for the month of January 1979, because of an intermittent communications problem. For the remaining four months of the reporting period (November, December of 1978, and February, March of 1979), the total incident solar energy was 45.99 million Btu, of which 13.12 million Btu were collected by the solar energy system. Solar energy satisfied 25 percent of the DHW requirements and 22 percent of the space heating requirements. The solar energy system provided an electrical savings of 4.26 million Btu.

A total of 45.99 million Btu of incident solar energy was measured in the collector array plane of 45 degrees to the horizontal, during the reporting period. At times when the collector array was operating, there were 34.58 million Btu incident on the array. The measured average daily incident solar energy per unit area in the plane of the collector array was 1089 million Btu per square foot per day, which is less than one percent below the long-term average.

2.2 Conclusions

During the reporting period, the solar energy system performed somewhat poorer than expected. There were high storage losses, especially during November under low load conditions.

The electrical energy savings for the space heating subsystem were determined based on conventional heating using a heat pump.

3. SYSTEM DESCRIPTION

J. D. Evans, Inc., House A is one of two instrumented single-family residences in Columbia, Maryland. The home has approximately 2250 square feet of conditioned space. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 350 square feet. The array faces south at an angle of 45 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage and to the space heating and hot water loads. Solar energy is stored in the basement in a 1000-gallon steel storage tank. Incoming city water is preheated in a liquid-to-liquid heat exchanger located in the storage tank and then flows into a conventional 40-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, a heat exchanger within a heat pump and an electrical heating element in the air-distribution duct provide auxiliary energy for space heating. Similarly, an electrical heating element in the DHW tank provides auxiliary energy for water heating. The system, shown schematically in Figure 3-1, has three modes of solar operation.

Mode 1 - Collector-to-Storage: This mode activates when the temperature difference between the storage tank and the collector outlet is higher than 15°F. Water circulates from the storage tank through the collector until a temperature difference of less than 5°F is reached.

Mode 2 - Storage-to-Space Heating: This mode activates when thermal energy for space heating is requested by the room thermostat. Solar-heated water from storage circulates through a liquid-to-air heat exchanger in the space heating air duct. If solar energy is insufficient to satisfy the space heating load, the heat pump and/or the auxiliary electrical heating element will be activated. The electrical strip heater can also be manually operated without solar heating and heat pump operation.

Mode 3 - DHW Preheating: This mode is activated by drawing hot water from the system. Cold supply water is preheated in a liquid-to-liquid heat exchanger

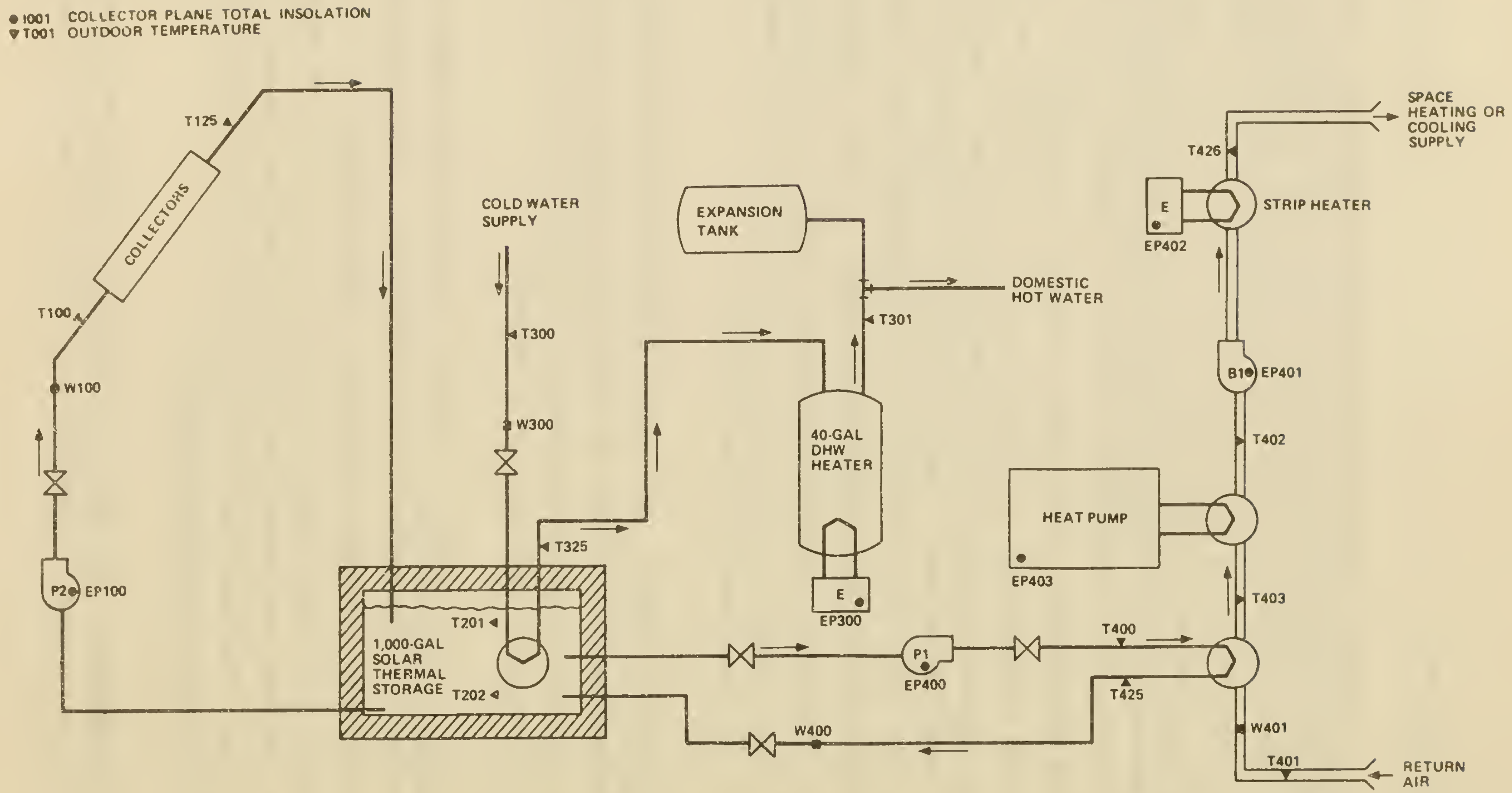


FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC
J. D. EVANS, INC., HOUSE A

located in the solar energy storage tank before flowing to the DHW tank. If the required DHW tank temperature is not maintained by solar preheating, auxiliary energy is provided by the electrical heating element in the DHW tank.

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the J. D. Evans, Inc., House A solar energy system is evaluated by calculating a set of primary performance factors which are based on those proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies. All performance factors and their definitions are listed in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for calculating the daily and monthly performance of each component subsystem. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the J. D. Evans, Inc., House A site and a detailed subsystem analysis are published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation (November 1978 through March 1979) are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

In addition, data are included in this report for which monthly reports are not available. This data is included with the intention of making this report as comprehensive as possible. Months for which no published monthly reports exist are shown in parentheses in the tables and figures. In the tables and figures in this report, an asterisk indicates that the value is not available for that month; N.A. indicates that the value is not applicable for this site.

5. PERFORMANCE ASSESSMENT

The performance of the J. D. Evans, Inc., House A solar energy system has been evaluated for the November 1978 through March 1979 time period. Two perspectives were taken in this assessment. The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. Where applicable, the expected values for solar energy used and system solar fraction are also shown. The expected values have been derived from a modified f-chart analysis which uses measured weather and subsystem loads as input. The f-chart is a performance estimation technique used for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin - Madison. The system mode used in the analysis is based on manufacturer's data and other known system parameters. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented.

The second view presents a more in-depth look at the performance of individual subsystems. Details relating to the performance of the collector array and storage subsystems are presented first, followed by details pertaining to the space heating and domestic hot water (DHW) subsystems. Included in this section are all parameters pertinent to the operation of each individual subsystem.

In addition to the overall system and subsystem analysis, this report also describes the equivalent energy savings contributed by the solar energy system. The overall system and individual subsystem energy savings are presented in Section 5.5.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore,

before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the J. D. Evans, Inc., House A site during the reporting period are presented in Table 5-1. Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

During the reporting period, the average daily total incident solar energy on the collector array was 1089 Btu per square foot per day. This was below the estimated average daily solar radiation for this geographical area during the reporting period of 1098 Btu per square foot per day for a south-facing plane with a tilt of 45 degrees to the horizontal. The average ambient temperature during the reporting period was 39°F as compared with the long-term average for November through March of 38°F. The average number of heating degree-days for the same period (based on a 65°F reference) was 775, as compared with the summation of the long-term averages of 800.

Monthly values of heating and cooling degree-days are derived from daily values of ambient temperature. They are useful indications of the system heating and cooling loads. Heating degree-days and cooling degree-days are computed as the difference between daily average temperature and 65°F. For example, if a day's average temperature was 60°F, then five heating degree-days are accumulated. Similarly, if a day's average temperature was 80°F, then 15 cooling degree-days are accumulated. The total number of heating and cooling degree-days is summed monthly.

TABLE 5-1. WEATHER CONDITIONS

J. D. EVANS, INC., HOUSE A

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA(1) (Btu/Ft^2)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
NOV	839	1069	46	46	570	567	0	0
DEC	1071	856	37	35	832	921	0	0
(JAN)	*	981	*	33	*	980	*	0
FEB	925	1205	26	35	1090	846	0	0
MAR	1519	1381	46	43	607	688	8	0
TOTAL					3099(2)	4002	8(2)	0
AVERAGE	1089	1098	39(2)	38	775(2)	800	2(2)	0

* - Denotes unavailable data

(1) In collector array plane and azimuth, unless otherwise indicated in Section 5.1

(2) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the useful energy delivered to the loads (excluding losses in the system), both solar and auxiliary thermal energies. The portion of the total load provided by solar energy is defined as the solar fraction of the load.

The thermal performance of the J. D. Evans, Inc., House A solar energy system is presented in Table 5-2. This performance assessment is based on the 4-month period from November 1978 through December 1978 and from February 1979 through March 1979. January 1979 data is not available. During the reporting period, a total of 13.12 million Btu of solar energy was collected and the total system load was 38.10 million Btu. The measured amount of solar energy delivered to the load subsystems was 8.51 million Btu or 4.1 million Btu less than the expected value. The measured system solar fraction was 22 percent as compared to an expected value of 33 percent.

Figure 5-1 illustrates the flow of solar energy from the point of collection to the various points of consumption and loss for the reporting period. The numerical values account for the quantity of energy corresponding with the transport, operation, and function of each major element in the J. D. Evans, Inc., House A solar energy system for the total reporting period.

Solar energy distribution flowcharts for each month of the reporting period are presented in Appendix D.

Table 5-3 summarizes solar energy distribution and provides a percentage breakdown. For the period November 1978 through March 1979 (except January 1979), the load subsystems consumed 65 percent of the energy collected and 36 percent was lost. (Energy in storage was lowered by an amount equivalent to one percent of the collected energy.) Appendix E contains the monthly solar energy percentage distributions. Transport losses were not determined.

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY

J. D. EVANS, INC., HOUSE A

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
NOV	2.05	4.20	2.0	0.84	47	20
DEC	3.94	12.04	3.7	3.30	30	28
(JAN)	*	*	*	*	*	*
FEB	2.46	16.43	2.5	1.28	15	8
MAR	4.67	5.43	4.4	3.09	78	56
TOTAL	(1) 13.12	38.10	12.6	8.51		
AVERAGE	(1) 3.28	9.53	3.15	2.13	33	22

* - Denotes unavailable data

(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

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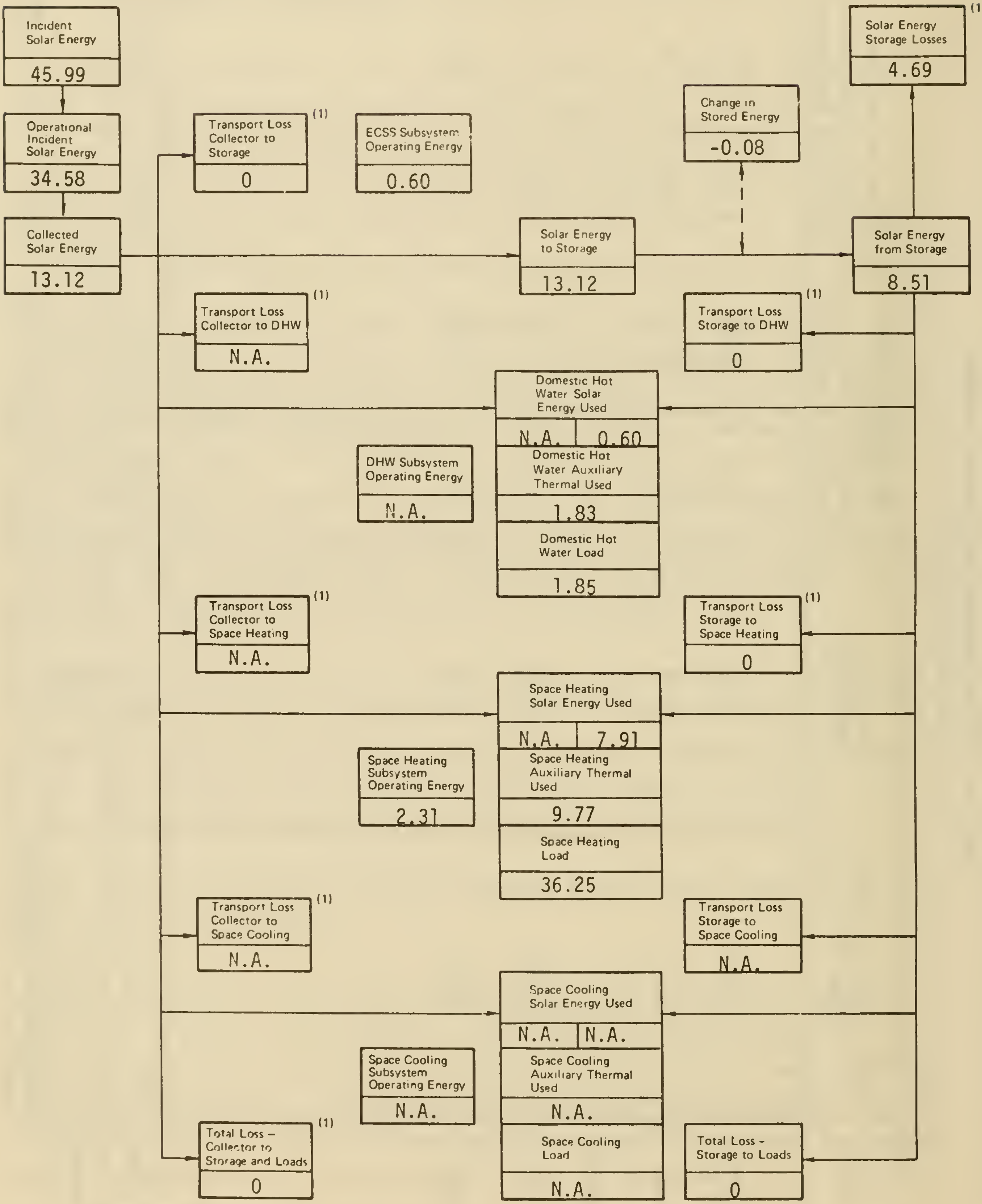
FIGURE 5-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - SUMMARY

J. D. EVANS, INC., HOUSE A



• Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

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TABLE 5-3. SOLAR ENERGY DISTRIBUTION - SUMMARY NOVEMBER 1978 - MARCH 1979
J. D. EVANS, INC., HOUSE A

- 13.12 million Btu / 100% TOTAL SOLAR ENERGY COLLECTED
  - 8.51 million Btu / 65% SOLAR ENERGY TO LOADS
    - 0.60 million Btu / 5% SOLAR ENERGY TO DHW SUBSYSTEM
    - 7.91 million Btu / 60% SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. million Btu / % SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 4.69 million Btu / 36% SOLAR ENERGY LOSSES
    - 4.69 million Btu / 36% SOLAR ENERGY LOSS FROM STORAGE
    - 0 million Btu / % SOLAR ENERGY LOSS IN TRANSPORT
      - 0 million Btu / % COLLECTOR TO STORAGE LOSS
      - N.A. million Btu / % COLLECTOR TO LOAD LOSS
        - N.A. million Btu / % COLLECTOR TO DHW LOSS
        - N.A. million Btu / % COLLECTOR TO SPACE HEATING LOSS
        - N.A. million Btu / % COLLECTOR TO SPACE COOLING LOSS
      - 0 million Btu / % STORAGE TO LOAD LOSS
        - 0 million Btu / % STORAGE TO DHW LOSS
        - 0 million Btu / % STORAGE TO SPACE HEATING LOSS
        - N.A. million Btu / % STORAGE TO SPACE COOLING LOSS
  - -0.08 million Btu / -1% SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

The solar energy coefficient of performance (COP) is indicated in Table 5-4. The COP simply provides a numerical value for the relationship of solar energy collected or transported or used and the energy required to perform the transition. The greater the COP value, the more efficient the subsystem. The solar energy system at the J. D. Evans, Inc., House A site functioned at a weighted average COP value of 11.35 for the reporting period November 1978 through March 1979 (January 1979 excluded).

5.3 Subsystem Performance

The J. D. Evans, Inc., House A solar energy installation may be divided into three subsystems:

1. Collector Array and Storage
2. Domestic Hot Water (DHW)
3. Space Heating

Each subsystem is evaluated and analyzed by the techniques defined in Section 4 in order to produce the monthly performance reports. This section presents the results of integrating the monthly data available on the three subsystems for the period November 1978 through March 1979.

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the J. D. Evans, Inc., House A site is presented in Table 5-5 for the reporting period November 1978 through March 1979. The total incident solar radiation on the collector array for the reporting period (excluding January 1979) was 45.99 million Btu. During the period the collector loop was operating the total insolation amounted to 34.58 million Btu. The total collected solar energy for the period was 13.12 million Btu, resulting in a collector array efficiency of 29 percent, based on total incident insolation. Solar energy delivered from the collector

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE
J. D. EVANS, INC., HOUSE A

MONTH	SOLAR ENERGY SYSTEM COP	COLLECTOR ARRAY SUBSYSTEM SOLAR COP	DOMESTIC HOT WATER SUBSYSTEM SOLAR COP	SPACE HEATING SUBSYSTEM SOLAR COP	SPACE COOLING SUBSYSTEM SOLAR COP
NOV	8.40	22.78	N.A.	84.44	N.A.
DEC	13.20	20.74	N.A.	53.00	N.A.
(JAN)	*	*	N.A.	*	N.A.
FEB	9.14	22.36	N.A.	37.67	N.A.
MAR	11.88	22.24	N.A.	55.69	N.A.
WEIGHTED AVERAGE	11.35	21.87	N.A.	52.73	N.A.

* - Denotes unavailable data
N.A. - Denotes not applicable data

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TABLE 5-5. COLLECTOR ARRAY PERFORMANCE

J. D. EVANS, INC., HOUSE A

MONTH	INCIDENT SOLAR ENERGY (Million Btu)	COLLECTED SOLAR ENERGY (Million Btu)	COLLECTOR ARRAY EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY (Million Btu)	OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)
NOV	8.81	2.05	23	5.19	39
DEC	11.62	3.94	34	9.71	41
(JAN)	*	*	*	*	*
FEB	9.07	2.46	27	6.63	37
MAR	16.49	4.67	28	13.05	36
TOTAL	(1) 45.99	13.12		34.58	
AVERAGE	(1) 11.50	3.28	29	8.65	38

* - Denotes unavailable data

(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

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array to storage was 13.12 million Btu. Operating energy required by the collector loop was 0.60 million Btu.

Collector array efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; therefore, the energy is not collected. In this approach, collector array performance is described by comparing the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s/Q_i$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5-5.

The second approach assumes the efficiency is based upon the incident solar energy during the periods of collection only.

Evaluating collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yield operational collector efficiency. Operational collector efficiency, η_{co}, is computed as follows:

$$\eta_{co} = Q_s/(Q_{oi} \times \frac{A_p}{A_a})$$

where: Q_s = collected solar energy

Q_{oi} = operational incident energy

A_p = gross collector area (product of the number of collectors and the total envelope area of one unit)

A_a = gross collector array area (total area perpendicular to the solar flux vector, including all mounting, connecting and transport hardware)

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 5-5. This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5-5.

5.3.1.2 Storage

Storage performance data for the J. D. Evans, Inc., House A site for the reporting period is shown in Table 5-6. Results of analysis of solar energy losses during transport and storage are shown in Table 5-7.

TABLE 5-6. STORAGE PERFORMANCE
J. D. EVANS, INC., HOUSE A

MONTH	ENERGY TO STORAGE (Million Btu)	ENERGY FROM STORAGE (Million Btu)	CHANGE IN STORED ENERGY (Million Btu)	STORAGE EFFICIENCY (%)	STORAGE AVERAGE TEMPERATURE (°F)	EFFECTIVE STORAGE HEAT LOSS COEFFICIENT (Btu/Hr -- °F)
NOV	2.05	0.84	-0.58	13	133	N.A.
DEC	3.94	3.30	-0.02	84	92	N.A.
(JAN)	*	*	*	*	*	N.A.
FEB	2.46	1.28	0.43	69	87	N.A.
MAR	4.67	3.09	0.09	68	112	N.A.
TOTAL	(1) 13.12	8.51	-0.08			
AVERAGE	(1) 3.28	2.13	-0.02	64	106	N.A.

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* - Denotes unavailable data
N.A. - Denotes not applicable data
(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

TABLE 5-7. SOLAR ENERGY LOSSES – STORAGE AND TRANSPORT
J. D. EVANS, INC., HOUSE A

	MONTH							
	NOV	DEC	JAN	FEB	MAR	TOTAL(1)		
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	2.05	3.94	*	2.46	4.67	13.12		
2. SE TO STORAGE (million Btu)	2.05	3.94	*	2.46	4.67	13.12		
3. LOSS – COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	0	0	*	0	0	0		
4. CHANGE IN STORED ENERGY (million Btu)	-0.58	-0.02	*	0.43	0.09	-0.08		
5. SOLAR ENERGY – STORAGE TO DHW SUBSYSTEM (million Btu)	0.08	0.12	*	0.15	0.25	0.60		
6. SOLAR ENERGY – STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	0.76	3.18	*	1.13	2.84	7.91		
7. SOLAR ENERGY – STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		
8. LOSS FROM STORAGE (%) $\frac{2-(4+5+6+7)}{2}$	87	17	*	30	32	36		
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	0.08	0.12	*	0.15	0.25	0.60		
10. LOSS – STORAGE TO HWSE (%) $\frac{5-9}{5}$	0	0	*	0	0	0		
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	0.76	3.18	*	1.13	2.84	7.91		
12. LOSS – STORAGE TO HSE (%) $\frac{6-11}{6}$	0	0	*	0	0	0		

* - Denotes unavailable data

N.A. - Denotes not applicable data

(1) Summation based on 4-month data: November, December (1978); February, March (1979)

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During the reporting period (excluding January 1979), total solar energy delivered to storage was 13.12 million Btu. There were 8.51 million Btu delivered from storage to the DHW and space heating subsystems. Energy loss from storage was 4.69 million Btu. This loss represented 36 percent of the energy delivered to storage. The storage efficiency was 64 percent: This is calculated as the ratio of the sum of the energy removed from storage and the change in stored energy, to the energy delivered to storage. The average storage temperature for the period was 106°F.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage, and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy to the energy to storage is defined as storage efficiency, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si}$$

where:

ΔQ = change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

Q_{so} = energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} = energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

5.3.2 Domestic Hot Water (DHW) Subsystem

The DHW subsystem performance for the J. D. Evans, Inc., House A site for the reporting period is shown in Table 5-8. The DHW subsystem consumed 0.60 million Btu of solar energy and 1.83 million Btu of auxiliary electrical energy to satisfy a hot water load of 1.85 million Btu. The solar fraction of this load was 25 percent.

The performance of the DHW subsystem is described by comparing the amount of solar energy supplied to the subsystem with the total energy required by the subsystem. The total energy required by the subsystem consists of both solar energy and auxiliary thermal energy. The DHW load is defined as the amount of energy required to raise the mass of water delivered by the DHW subsystem between the temperature at which it entered the subsystem and its delivery temperature. The DHW solar fraction is defined as the portion of the DHW load which is supported by solar energy.

5.3.3 Space Heating Subsystem

The space heating subsystem performance for the J. D. Evans, Inc., House A site for the reporting period is shown in Table 5-9. The space heating subsystem consumed 7.91 million Btu of solar energy and 13.95 million Btu of auxiliary electrical energy to satisfy a space heating load of 36.25 million Btu. The solar fraction of this load was 22 percent.

During the reporting period, the space heating load was satisfied by solar energy and heat pump ambient thermal energy. The auxiliary electrical strip heater was not used. Table 5-10 shows energy contribution towards the space heating load from solar, heat pump, and electrical strip heater sources for the reporting period. It shows a total solar energy contribution of 7.91 million Btu and a heat pump contribution of 28.34 million Btu.

The performance of the space heating subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to

TABLE 5-8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

J. D. EVANS, INC., HOUSE A

MONTH	DOMESTIC HOT WATER LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
NOV	0.24	0.08	0.27	0.27	N.A.	34
DEC	0.49	0.12	0.50	0.50	N.A.	27
(JAN)	*	*	*	*	N.A.	*
FEB	0.63	0.15	0.64	0.64	N.A.	21
MAR	0.49	0.25	0.42	0.42	N.A.	41
TOTAL (1)	1.85	0.60	1.83	1.83	N.A.	
AVERAGE (1)	0.46	0.15	0.46	0.46	N.A.	25

* - Denotes unavailable data
N.A. - Denotes not applicable data
(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

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TABLE 5-9 SPACE HEATING SUBSYSTEM PERFORMANCE
J. D. EVANS, INC., HOUSE A

MONTH	SPACE HEATING LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
NOV	3.96	0.76	1.01	1.44	N.A.	19
DEC	11.55	3.18	2.70	3.86	N.A.	28
(JAN)	*	*	*	*	N.A.	*
FEB	15.80	1.13	5.40	7.71	N.A.	7
MAR	4.94	2.84	0.66	0.94	N.A.	57
TOTAL	(1) 36.25	7.91	9.77	13.95	N.A.	
AVERAGE	(1) 9.06	1.98	2.44	3.49	N.A.	22

* - Denotes unavailable data
(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

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TABLE 5-10. SPACE HEATING ENERGY CONTRIBUTION

MONTH	SPACE HEATING LOAD (Million Btu)	ENERGY CONTRIBUTION (Million Btu)		
		SOLAR	HEAT PUMP	ELECTRIC STRIP HEATER
NOV	3.96	0.76	3.20	0
DEC	11.55	3.18	8.37	0
(JAN)	*	*	*	*
FEB	15.80	1.13	14.67	0
MAR	4.94	2.84	2.10	0
TOTAL (1)	36.25	7.91	28.34	0
AVERAGE (1)	9.06	1.98	7.09	0

* - Denotes unavailable data

(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

satisfy the total space heating load. The energy required to satisfy the total load consists of the solar energy, the heat pump ambient thermal energy and the strip heater thermal energy. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction.

5.4 Operating Energy

Measured values of the J. D. Evans, Inc., House A solar energy system and subsystem operating energy for the reporting period are presented in Table 5-11. A total of 2.91 million Btu of operating energy was consumed by the entire system during the reporting period, except January 1979.

Operating energy for a solar energy system is defined as the amount of electrical energy required to support the subsystems without affecting their thermal state.

Total system operating energy for the J. D. Evans, Inc., House A site is the energy required to support the energy collection and storage subsystem (ECSS), the DHW subsystem, and the space heating subsystem. With reference to the system schematic (Figure 3-1), the ECSS operating energy includes energy required by pump P2 in the collector/storage loop. The space heating subsystem operating energy consists of energy required by pump P1 in the storage/heat exchanger loop and energy required by blower B1 in the space heating duct.

5.5 Energy Savings

Energy savings for the J. D. Evans, Inc., House A site for the reporting period are presented in Table 5-12. For this period except January 1979, the total savings on electrical energy were 4.26 million Btu for a monthly average of 1.07 million Btu.

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide

TABLE 5-11. OPERATING ENERGY
J. D. EVANS, INC., HOUSE A

MONTH	ENERGY COLLECTION AND STORAGE OPERATING ENERGY (Million Btu)	DOMESTIC HOT WATER OPERATING ENERGY (Million Btu)	SPACE HEATING OPERATING ENERGY (Million Btu)	SPACE COOLING OPERATING ENERGY (Million Btu)	TOTAL SYSTEM OPERATING ENERGY (Million Btu)
NOV	0.09	N.A.	0.18	N.A.	0.27
DEC	0.19	N.A.	0.76	N.A.	0.95
(JAN)	*	N.A.	*	N.A.	*
FEB	0.11	N.A.	0.95	N.A.	1.06
MAR	0.21	N.A.	0.42	N.A.	0.63
TOTAL	(1) 0.60	N.A.	2.31	N.A.	2.91
AVERAGE	(1) 0.15	N.A.	0.58	N.A.	0.73

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* - Denotes unavailable data
N.A. - Denotes not applicable data
(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

TABLE 5-12. ENERGY SAVINGS

J. D. EVANS, INC., HOUSE A

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPER-ATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING				
		ELEC-TRICAL	FOSSIL FUEL	ELEC-TRICAL	FOSSIL FUEL	ELEC-TRICAL	FOSSIL FUEL		ELEC-TRICAL	FOSSIL FUEL
NOV	0.84	0.34	N.A.	0.08	N.A.	N.A.	N.A.	0.10	0.34	N.A.
DEC	3.30	1.76	N.A.	0.12	N.A.	N.A.	N.A.	0.25	1.70	N.A.
(JAN)	*	*	N.A.	*	N.A.	N.A.	N.A.	*	*	N.A.
FEB	1.28	0.77	N.A.	0.15	N.A.	N.A.	N.A.	0.14	0.81	N.A.
MAR	3.09	1.37	N.A.	0.25	N.A.	N.A.	N.A.	0.26	1.41	N.A.
TOTAL	(1) 8.51	4.24	N.A.	0.60	N.A.	N.A.	N.A.	0.75	4.26	N.A.
AVERAGE	(1) 2.13	1.06	N.A.	0.15	N.A.	N.A.	N.A.	0.19	1.07	N.A.

* - Denotes unavailable data

N.A. - Denotes not applicable data

(1) Summation and averages based on 4-month data: November, December (1978); February, March (1979)

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solar energy to the load subsystems is subtracted from the solar energy contribution to determine net savings.

The auxiliary source at the J. D. Evans, Inc., House A site consists of a DHW electrical heater, a heat pump, and an electrical strip heater. The electrical energy savings for the space heating subsystem were determined based on conventional heating using a heat pump.

6. REFERENCES

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APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).

- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.

- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.

- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.

- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.

- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.

- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.

- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- <u>OPERATING ENERGY</u> (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.

- <u>AUXILIARY THERMAL USED</u> (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- <u>AUXILIARY ELECTRICAL FUEL</u> (HAE) is the amount of electrical energy supplied directly to the subsystem.

- <u>ELECTRICAL ENERGY SAVINGS</u> (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- <u>BUILDING TEMPERATURE</u> (TB) is the average heated space dry bulb temperature.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS

J. D. EVANS, INC., HOUSE A

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds. This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: The total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{CLAREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Btu per square foot per hour, CLAREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liqujd system ΔH is generally given by

$$\Delta H = \bar{C}_p\ \Delta T$$

where $\bar{C}_p$ is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in Btu/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to Btu/min.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therfore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: SENSOR IDENTIFICATION (MEASUREMENT) NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-1

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ T401 \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma\ T001 \times \Delta\tau$$

FOR $\pm$ 3 HOURS FROM SOLAR NOON

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

$$SE = (1/60) \times \Sigma\ I001 \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON ARRAY (BTU)

$$SEA = SE \times CLAREA$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma\ [I001 \times CLAREA] \times \Delta\tau$$

WHEN THE COLLECTOR LOOP IS ACTIVE

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times HWD \times (T125 - T100)] \times \Delta\tau$$

WHERE M100 IS THE COLLECTOR FLUID MASS FLOW RATE AND HWD IS A FUNCTION CALCULATING CHANGE IN FLUID ENTHALPY OVER THE RANGE T125 - T100

COLLECTED SOLAR ENERGY PER UNIT AREA (BTU/FT^2)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY (PERCENT

$$CAREFF = (SECA/SEA) \times 100$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = (56.88) \times \Sigma\, EP100 \times \Delta\tau$$

STORAGE TEMPERATURE (°F)

$$TST = (1/60) \times \Sigma\, [(T201 + T202)/2] \times \Delta\tau$$

ENERGY TO STORAGE (BTU)

$$STEI = SECA$$

ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\, [M300 \times HWD\ (1325 - T300) \times \Delta\tau] + \Sigma\, [M400 \times HWD\ (T400 - T425) \times \Delta\tau]$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP \times (TST \times RHO \times CP - TST_p \times RHO_p \times CP_p)$$

WHERE THE SUBSCRIPT $_p$ INDICATES VALUES TAKEN FROM A PREVIOUS REFERENCE HOUR

STORAGE EFFICIENCY (PERCENT)

$$STEFF = [(STECH + STEO)/STEI] \times 100$$

ENERGY DELIVERED TO LOAD FROM ECSS (BTU)

$$CSEO = STEO$$

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = CSEO$$

ECSS SOLAR CONVERSION EFFICIENCY (PERCENT)

$$CSCEF = SEL/SEA \times 100$$

HOT WATER CONSUMPTION (GALLONS)

$$HWCSM = \Sigma\, WD300 \times \Delta\tau$$

WHERE WD300 IS THE TIME DERIVATIVE OF THE TOTALIZING FLOWMETER

HOT WATER LOAD (BTU)

$$HWL = \Sigma\ [M300 \times HWD\ (T301 - T300)] \times \Delta\tau$$

HOT WATER SOLAR ENERGY (BTU)

$$HWSE = \Sigma\ [M300 \times HWD\ (T325 - T300)] \times \Delta\tau$$

HOT WATER AUXILIARY ELECTRICAL ENERGY (BTU)

$$HWAE = 56.88 \times \Sigma\ EP300 \times \Delta\tau$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = HWAE$$

HOT WATER SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = HWSE$$

SUPPLY WATER TEMPERATURE (°F) - MASS FLOW WEIGHTED

$$TSW = \frac{\Sigma\ T300 \times M300 \times \Delta\tau}{\Sigma\ M300 \times \Delta\tau}$$

HOT WATER TEMPERATURE (°F) - MASS FLOW WEIGHTED

$$THW = \frac{\Sigma\ T301 \times M300 \times \Delta\tau}{\Sigma\ M300 \times \Delta\tau}$$

HOT WATER SOLAR FRACTION (PERCENT)

$$HWSFR = 100 \times HWTKSE/(HWTKSE + HWTKAUX)$$

WHERE $HWTKSE = (HWSFR\_P / 100) * (TANKV - HWSE - HWAT) + HWSE$

$HWTKAUX = (1 - HWSFR\_P / 100) * (TANKV - HWSE - HWAT) + HWAT$

$HWSFR\_P$ = PAST HWSFR VALUE

$TANKV = HWCAP \times [RHO\ (THW) \times CP\ (THW) \times THW - RHO\ (TSW) \times CP\ (TSW) \times TSW]$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSW = \Sigma\ [M400 \times HWD\ (T400 - T425)] \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HAE = 56.88 \times [\Sigma\ (EP402 + EP403) \times \Delta\tau]$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = 56.88 \times [\Sigma\ (EP402 + EP403 \times COMPEFF) \times \Delta\tau]$$

WHERE COMPEFF IS THE HEAT PUMP COMPRESSOR EFFICIENCY (LONG-TERM AVERAGE). A VALUE OF 0.7 IS USED WHERE SPECIFIC DATA IS NOT AVAILABLE.

HEAT PUMP HEATING LOAD (BTU)

$$HPHL = 56.88 \times EP403 \times HPCOP$$

WHERE HPCOP IS THE HEAT PUMP COEFFICIENT OF PERFORMANCE AND IS DERIVED FROM:

$$HPCOP = 1.303 + 0.033 \times TA - 0.000197 \times TA^2$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = HSE + HPHL + 56.88 \times \Sigma\ EP402 \times \Delta\tau$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$HSFR = 100 \times HSE/HL$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.88 \times \Sigma\ (EP400 + EP401) \times \Delta\tau$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = HSE/(HPFRAC \times HPCOP + 1 - HPFRAC) - 56.88 \times \Sigma\ EP400 \times \Delta\tau$$

WHERE HPFRAC IS THE FRACTION OF TOTAL LOAD PROVIDED BY HEAT PUMP AND IS GIVEN BY

$$HPFRAC = 1.11 \times CAPN\ (TA) \times \left(\frac{TB - 40}{TB - TA}\right)$$

AND, $CAPN\ (TA) = 0.325 + 0.0162 \times TA - 0.00005 \times TA^2$

SYSTEM LOAD (BTU)

$$SYSL = HWL + HL$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$SFR = (HWSFR \times HWL + HSFR \times HL)/SYSL$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAT + HAT

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE + HAE

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE + HSVE - CSOPE

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

SITE: J.D. EVANS 56. LOCATION: COLUMBIA MD

ANALYST: M. FU FDRIVE NO.: 4.

COLLECTOR TILT: 45.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 38.85 (DEGREES) RUN DATE: 6/04/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1388.	586.	0.42232	1.673	981.	980	0	33.
FEB	1848.	841.	0.45488	1.434	1205.	846	0	35.
MAR	2438.	1161.	0.47635	1.189	1381.	688	0	43.
APR	3046.	1490.	0.48902	0.985	1467.	340	0	54.
MAY	3469.	1714.	0.49423	0.862	1478.	110	70	64.
JUN	3639.	1880.	0.51673	0.811	1525.	0	225	72.
JUL	3548.	1825.	0.51435	0.833	1520.	0	360	77.
AUG	3204.	1600.	0.49938	0.929	1487.	0	307	75.
SEP	2654.	1331.	0.50154	1.107	1473.	27	132	69.
OCT	2018.	999.	0.49507	1.369	1368.	250	14	57.
NOV	1494.	660.	0.44168	1.619	1069.	567	0	46.
DEC	1262.	498.	0.39448	1.721	856.	921	0	35.

LEGEND:

HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.

HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.

KBAR ==> RATIO OF HBAR TO HOBAR.

RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).

SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.

HDD ==> NUMBER OF HEATING DEGREE DAYS PER MONTH.

CDD ==> NUMBER OF COOLING DEGREE DAYS PER MONTH.

TBAR ==> AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.

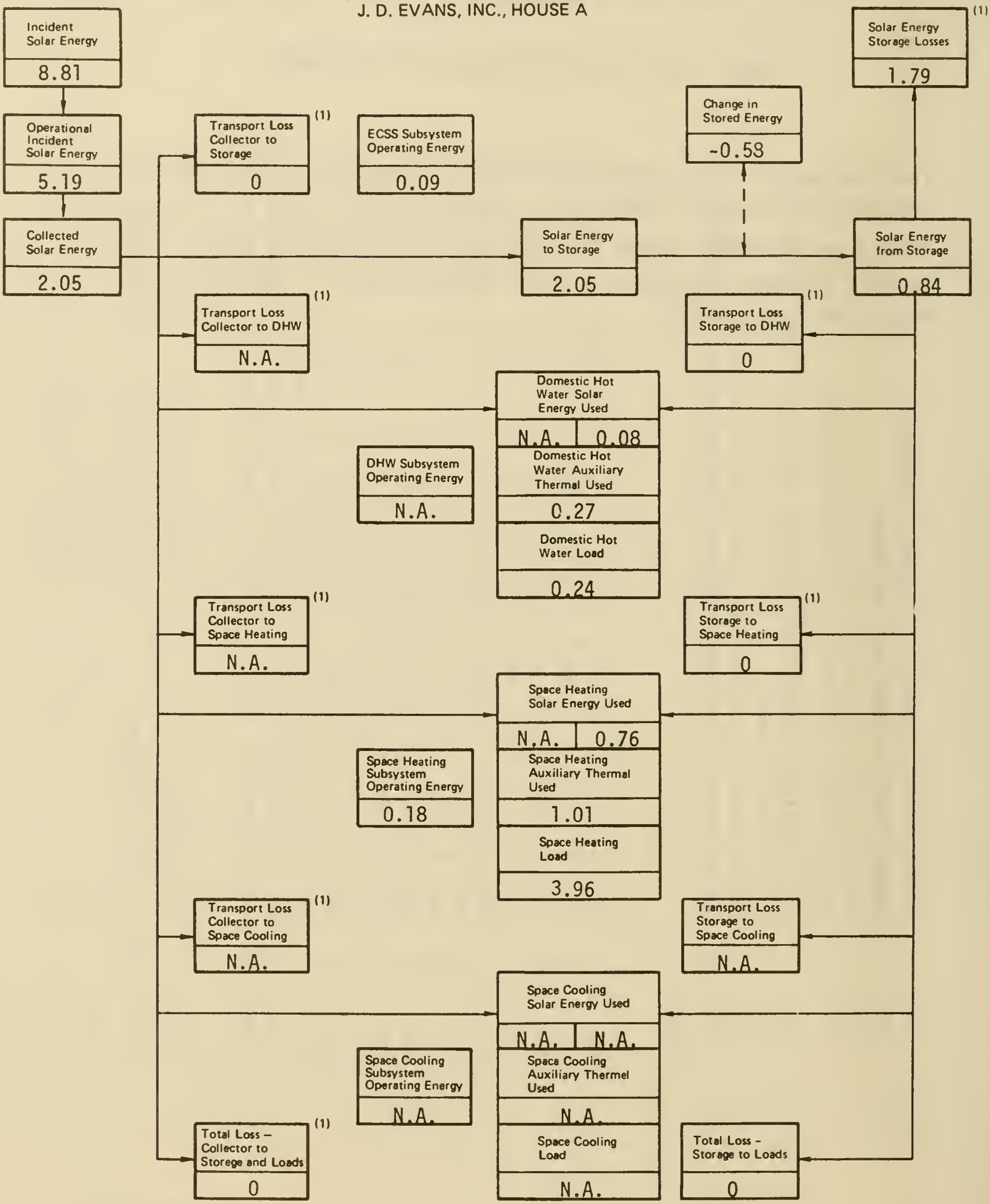
APPENDIX D

MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS

The flowcharts in this appendix depict the quantity of solar energy corresponding to each major component or characteristic of the J. D. Evans, Inc., House A solar energy system for 4 months of the reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.

FIGURE D-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - NOVEMBER 1978

J. D. EVANS, INC., HOUSE A



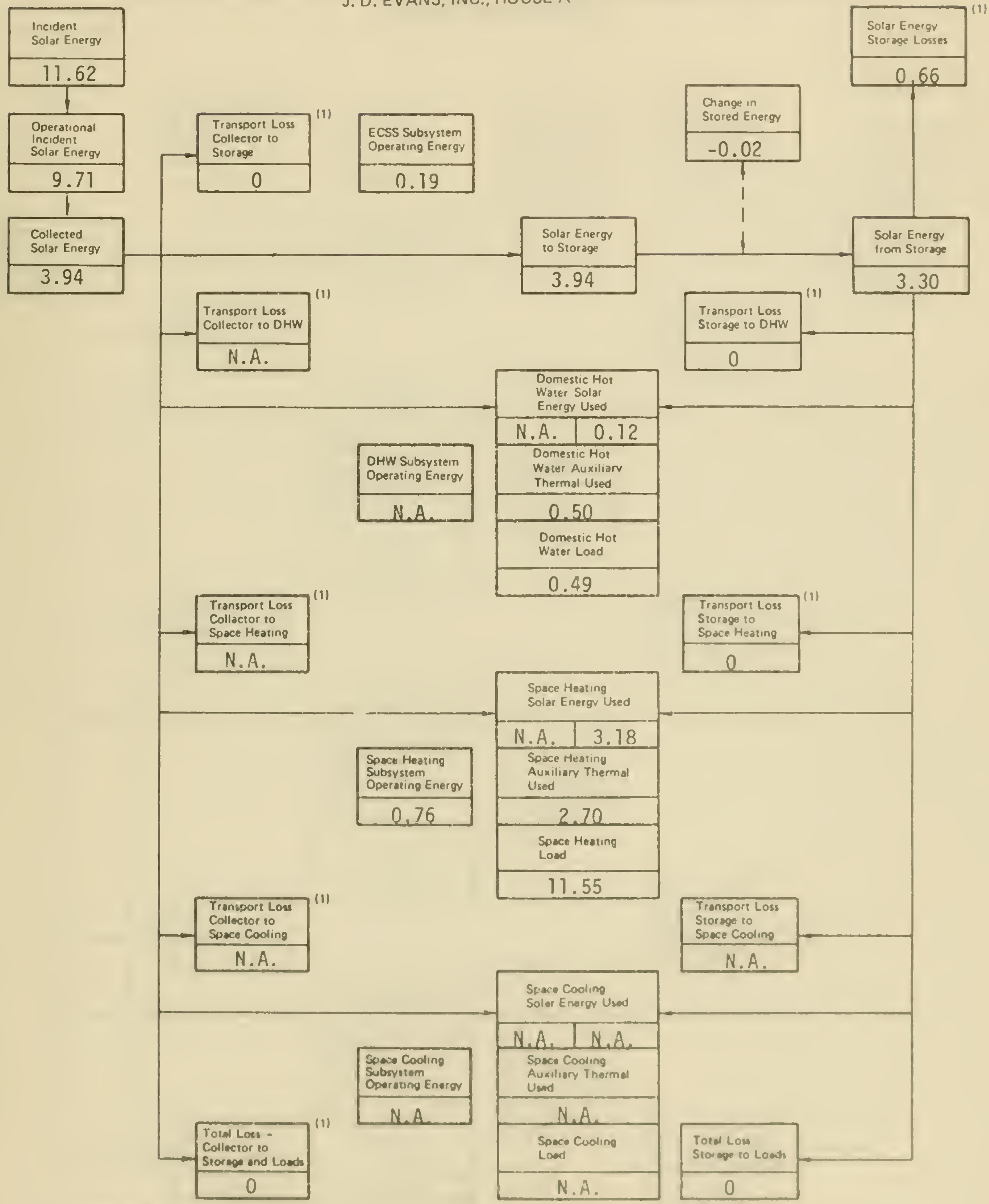
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

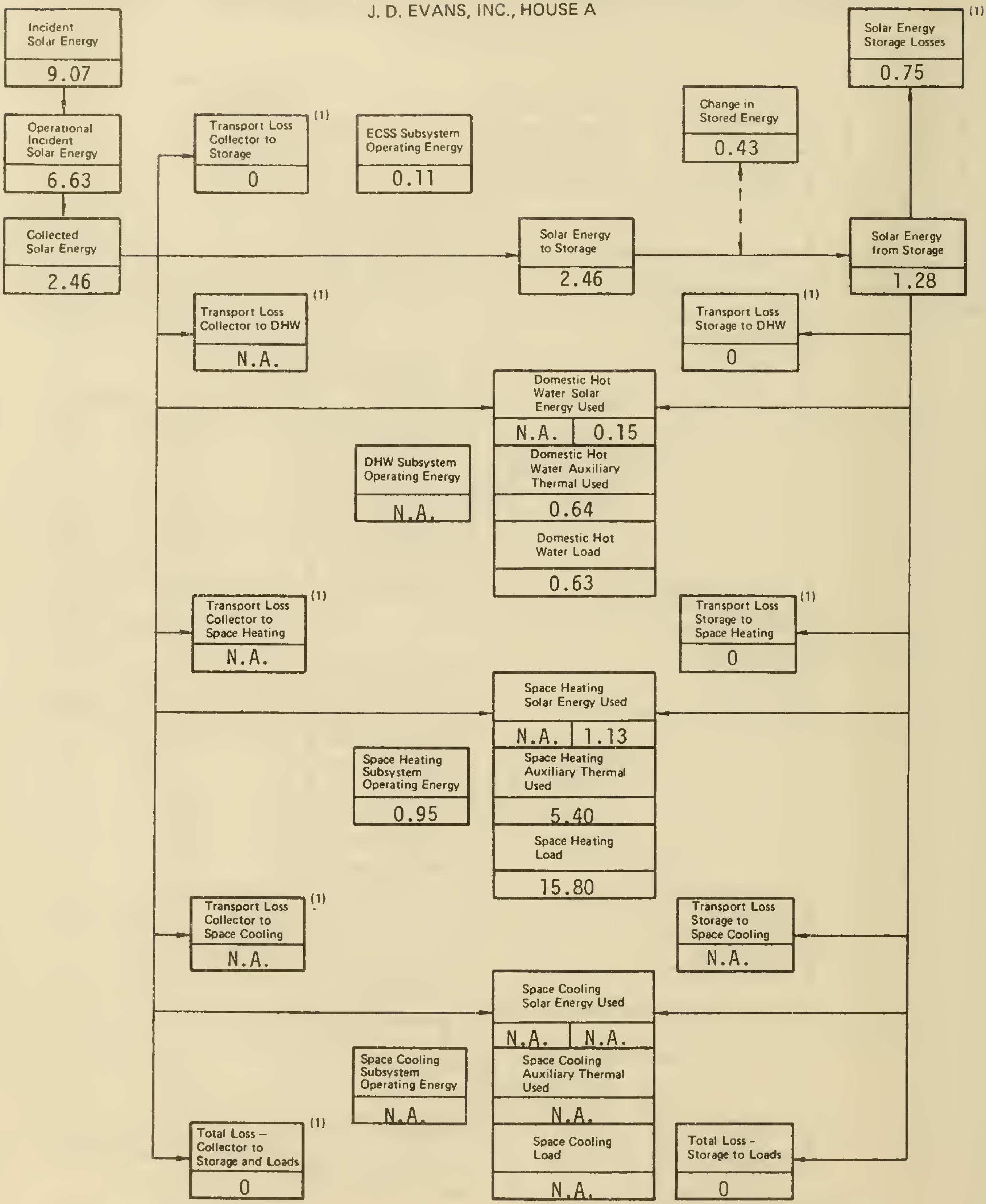
FIGURE D-2. SOLAR ENERGY (MILLION BTU DISTRIBUTION FLOWCHART - DECEMBER 1978
J. D. EVANS, INC., HOUSE A



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

FIGURE D-3. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - FEBRUARY 1979

J. D. EVANS, INC., HOUSE A



* Denotes Unavailable Data

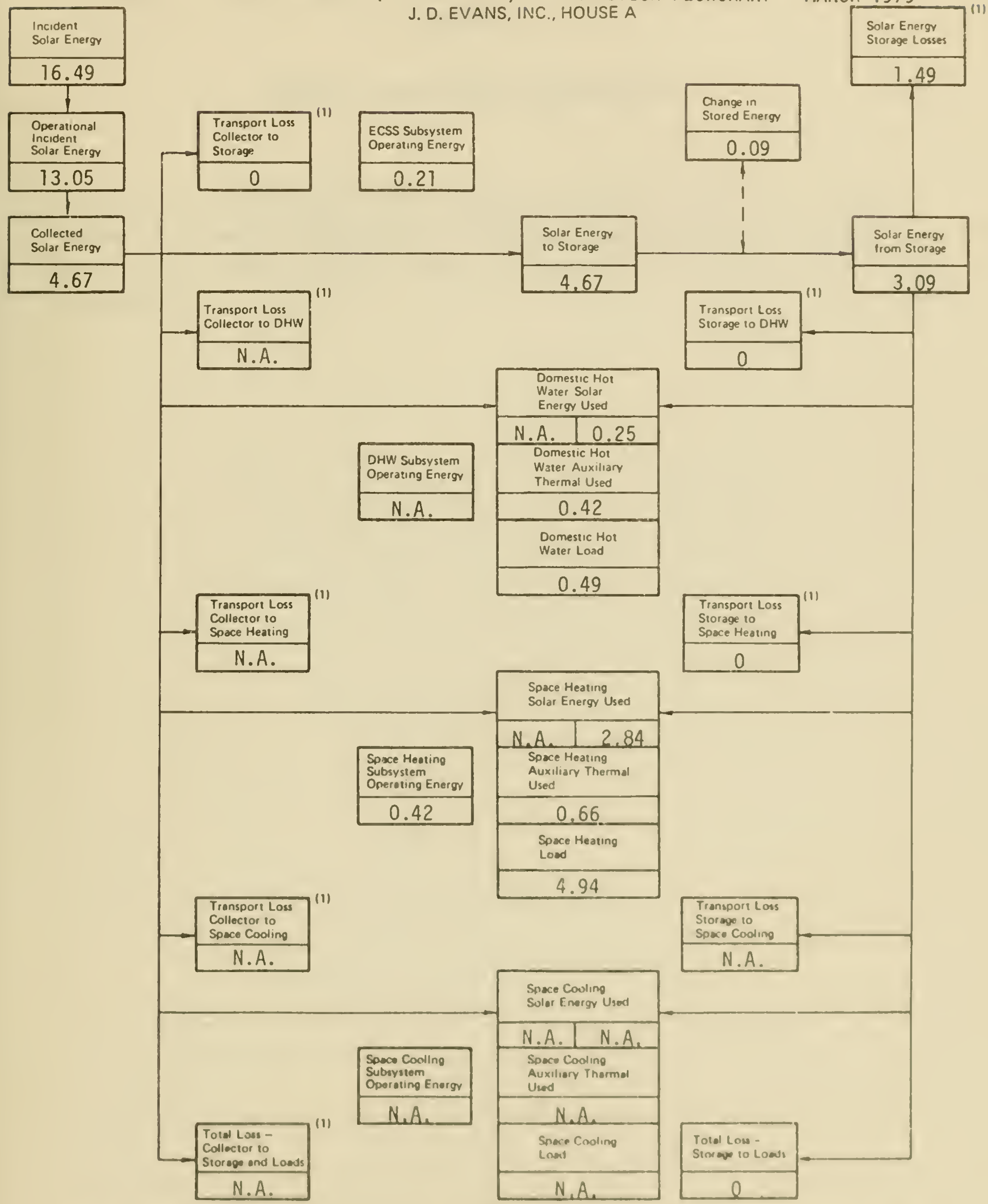
N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-4. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - MARCH 1979

J. D. EVANS, INC., HOUSE A



* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

APPENDIX E

MONTHLY SOLAR ENERGY DISTRIBUTIONS

The data tables provided in this appendix present an indication of solar energy distribution, intentional and unintentional, in the J. D. Evans, Inc., House A solar energy system. Tables are provided for 4 months of the reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION - NOVEMBER 1978
J. D. EVANS, INC., HOUSE A

2.05 million Btu / 100% — TOTAL SOLAR ENERGY COLLECTED

- 0.84 million Btu / 41 % — SOLAR ENERGY TO LOADS
  - 0.08 million Btu / 4% — SOLAR ENERGY TO DHW SUBSYSTEM
  - 0.76 million Btu / 37 % — SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
  - N.A. million Btu / % — SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
- 1.79 million Btu / 87 % — SOLAR ENERGY LOSSES
  - 1.79 million Btu / 87 % — SOLAR ENERGY LOSS FROM STORAGE
  - 0 million Btu / % — SOLAR ENERGY LOSS IN TRANSPORT
    - 0 million Btu / % — COLLECTOR TO STORAGE LOSS
    - N.A. million Btu / % — COLLECTOR TO LOAD LOSS
      - N.A. million Btu / % — COLLECTOR TO DHW LOSS
      - N.A. million Btu / % — COLLECTOR TO SPACE HEATING LOSS
      - N.A. million Btu / % — COLLECTOR TO SPACE COOLING LOSS
    - 0 million Btu / % — STORAGE TO LOAD LOSS
      - 0 million Btu / % — STORAGE TO DHW LOSS
      - 0 million Btu / % — STORAGE TO SPACE HEATING LOSS
      - N.A. million Btu / % — STORAGE TO SPACE COOLING LOSS
- -0.58 million Btu / -28 % — SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-2. SOLAR ENERGY DISTRIBUTION - DECEMBER 1978
J. D. EVANS, INC., HOUSE A

3.94 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
3.30 million Btu	84 %	SOLAR ENERGY TO LOADS
0.12 million Btu	3 %	SOLAR ENERGY TO DHW SUBSYSTEM
3.18 million Btu	81 %	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
0.66 million Btu	17 %	SOLAR ENERGY LOSSES
0.66 million Btu	17 %	SOLAR ENERGY LOSS FROM STORAGE
0 million Btu	%	SOLAR ENERGY LOSS IN TRANSPORT
0 million Btu	%	COLLECTOR TO STORAGE LOSS
N.A. million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
N.A. million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
0 million Btu	%	STORAGE TO LOAD LOSS
0 million Btu	%	STORAGE TO DHW LOSS
0 million Btu	%	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
-0.02 million Btu	-1 %	SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-3. SOLAR ENERGY DISTRIBUTION - FEBRUARY 1979
J. D. EVANS, INC., HOUSE A

2.46 million Btu / 100% — TOTAL SOLAR ENERGY COLLECTED

- 1.28 million Btu / 52 % — SOLAR ENERGY TO LOADS
  - 0.15 million Btu / 6 % — SOLAR ENERGY TO DHW SUBSYSTEM
  - 1.13 million Btu / 46 % — SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
  - N.A. million Btu / % — SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
- 0.75 million Btu / 31% — SOLAR ENERGY LOSSES
  - 0.75 million Btu / 31 % — SOLAR ENERGY LOSS FROM STORAGE
  - 0 million Btu / % — SOLAR ENERGY LOSS IN TRANSPORT
    - 0 million Btu / % — COLLECTOR TO STORAGE LOSS
    - N.A. million Btu / % — COLLECTOR TO LOAD LOSS
      - N.A. million Btu / % — COLLECTOR TO DHW LOSS
      - N.A. million Btu / % — COLLECTOR TO SPACE HEATING LOSS
      - N.A. million Btu / % — COLLECTOR TO SPACE COOLING LOSS
    - 0 million Btu / % — STORAGE TO LOAD LOSS
      - 0 million Btu / % — STORAGE TO DHW LOSS
      - 0 million Btu / % — STORAGE TO SPACE HEATING LOSS
      - N.A. million Btu / % — STORAGE TO SPACE COOLING LOSS
- 0.43 million Btu / 17% — SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-4. SOLAR ENERGY DISTRIBUTION - MARCH 1979
J. D. EVANS, INC., HOUSE A

Million Btu	%	
4.67	100%	TOTAL SOLAR ENERGY COLLECTED
3.09	66 %	SOLAR ENERGY TO LOADS
0.25	5 %	SOLAR ENERGY TO DHW SUBSYSTEM
2.84	61 %	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A.	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
1.49	32 %	SOLAR ENERGY LOSSES
1.49	32 %	SOLAR ENERGY LOSS FROM STORAGE
0	%	SOLAR ENERGY LOSS IN TRANSPORT
0	%	COLLECTOR TO STORAGE LOSS
N.A.	%	COLLECTOR TO LOAD LOSS
N.A.	%	COLLECTOR TO DHW LOSS
N.A.	%	COLLECTOR TO SPACE HEATING LOSS
N.A.	%	COLLECTOR TO SPACE COOLING LOSS
0	%	STORAGE TO LOAD LOSS
0	%	STORAGE TO DHW LOSS
0	%	STORAGE TO SPACE HEATING LOSS
N.A.	%	STORAGE TO SPACE COOLING LOSS
0.09	2 %	SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

*U.S. GOVERNMENT PRINTING OFFICE: 1980-640-189/4236. Region 4.